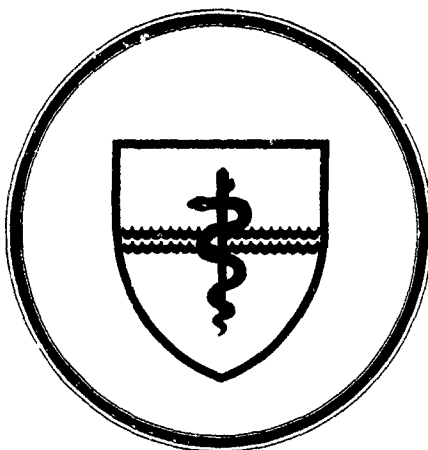


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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.



REPORT NUMBER 1097

SCOTOPIC SENSITIVITY WITH 10% OXYGEN

by

S. M. LURIA and Douglas R. KNIGHT

Naval Medical Research and Development Command
Research Work Unit M0100.001-1023

Released by:
C. A. Harvey, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

9 July 87

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SUMMARY PAGE

Problem: To compare night vision sensitivity of subjects breathing 21% and 10% oxygen.

Findings: Night vision was significantly reduced very quickly under 10% oxygen (P_{O_2} 76 torr). Since the level of carbon-dioxide expired by the subjects did not change, the degradation of vision was attributed solely to the reduction in oxygen and not to a change in blood levels of carbon-dioxide.

Application: The occupied compartments of nuclear submarines experience fluctuations of barometric pressure between 800 and 608 torr, the lowest pressure resulting from an engineering-induced, partial vacuum of 6 inches mercury. Submarine commanders may need to know the safe, minimum PO_2 for brief (up to 6 hours) occupancy in the greatest partial vacuum. This study indicates that PO_2 76 torr impairs the visual sensitivity for dimly lit targets.

ADMINISTRATIVE INFORMATION

This investigation was conducted under Naval Medical Research and Development Command Research Work Unit #M0100.001-1023. It was submitted for review on 8 June 1987 and approved for publication on 9 July 1987. It has been designated as Naval Submarine Medical Research Laboratory Report No. 1097.

Abstract

The night vision (scotopic) sensitivity of 6 subjects was measured while they were breathing either air (21% oxygen, PO_2 160 torr) or 10% oxygen, balance nitrogen (PO_2 76 torr). Continuous monitoring showed that the mean oxygen content in the arterial blood (SaO_2) dropped from 97% to 77% during the first seven minutes of breathing 10% oxygen, and there was a significant degradation of scotopic sensitivity. The reduced sensitivity was attributed solely to hypoxia with no contribution from hypocapnia.

Scotopic sensitivity with 10% oxygen

S. M. Luria and Douglas R. Knight

It has been suggested that vision is a very sensitive measure of a variety of toxicities and may be the most sensitive measure of oxygen deprivation (hypoxia) or other harmful effects (Halperin, et al, 1947; Carr, et al. 1966; Crews, 1966). Several climbers of Mt. Everest have commented on the noticeable dimming of vision under conditions of hypoxia (e.g., Hornbein, 1983; Griffith, et al., 1983).

In a series of papers whose publication began just before World War II, McFarland and his colleagues reported measurable degradations of visual thresholds when subjects were exposed to surprisingly small decrements of oxygen concentration; in a review, McFarland (1970) wrote that "some subjects manifest(ed) significant impairment at 4,000 to 5,000 feet altitude" (p. 305). This would correspond to a decrease in the arterial blood oxygen content of less than 5%.

Subsequent investigators have not agreed on the level of oxygen deprivation at which visual thresholds--or other measures--are affected. Weir et al (1973), for example, found no significant changes in dark adapted thresholds for identification of shapes at carboxyhemoglobin (COHb) (see Glossary of Terms) levels up to 20%; this is estimated to correspond to an altitude of 15,000 ft (McFarland, 1970, figure 2). Beard and Grandstaff (1970) found no reliable changes with COHb levels up to 7%, presumably corresponding to an altitude of 7,000 ft.; Stewart et al (1970) and Weir et al (1973) found no impairments in reaction time at COHb levels of 13%; Roche et al (1981) found that vigilance performance was not affected by 5% COHb, equivalent, as noted above, to an altitude of only about 5,000 ft.

We have not found decrements in the scotopic sensitivity of subjects breathing air containing only 13% oxygen for three hours

(Knight et al, 1987) or of subjects exposed for three hours to 200 ppm of carbon-monoxide (Luria and Schlichting, 1979), which raises the COHb level in the blood to about 15% (Stewart et al., 1970).

Since air containing 13% oxygen had no effects, we have, therefore, now tested the effects of breathing air containing only 10% oxygen in an attempt to find that oxygen level which does affect scotopic sensitivity and selected physiological indicators.

METHOD

Subjects

Six staff members of the laboratory, ranging in age from 28 to 57, volunteered. Those who required refractive corrections for reading wore their eyeglasses during the experiment.

Apparatus

The subjects breathed 21% oxygen (P_{O_2} 158 torr) or 10% oxygen (P_{O_2} 76 torr) through a two-way, non-rebreathing (Rudolph) valve (dead space, 15 ml) while wearing a nose-clip. Samples of the expired breath were collected from the Rudolph valve and analyzed by a Perkin-Elmer Mass Spectrometer, Model 1100. The end-tidal partial pressures of oxygen (P_{et,O_2}) and carbon-dioxide (P_{et,CO_2}) were the products of the barometric pressure multiplied by the end-tidal concentration of those gases in a saturated gas mixture. The oxygen saturation of arterial blood (SaO_2) was measured by a Novamatrix Pulse Oximeter, model 500, with the sensor placed on the index finger. A single-lead (modified V_5) electrocardiogram was continuously monitored on an oscilloscope.

The subjects, who were positioned 60 cm from a ground glass screen, used a chin-rest to steady their heads while viewing the display with the right eye. The test stimulus was a circle of light subtending 0.5 deg visual angle, projected onto the screen in the wall of a light-proof viewing chamber. It was presented 10 deg to the left of a pin-point fixation light and flickered at 2 cps to

facilitate recognition. The light source was a projection bulb, and its intensity was varied with neutral density filters. The luminances of the stimuli were measured with a Spectra Pritchard Photometer, Model 1980.

Procedure

Each subject was tested twice on separate days, according to a double-blind protocol. Half the subjects were first given 21% oxygen, and half first breathed 10% oxygen. Neither the subjects nor the experimenter were informed as to the gas mixture which was being administered. The experimenter was unquestionably unaware of this, but the subjects, of course, reported afterwards that they had had symptomatic cues.

Subjects were dark adapted outside the viewing chamber by wearing light-proof goggles for 20 minutes. They were then led into the viewing chamber and the SaO_2 sensing device was placed on the finger, after which the viewing chamber was closed. They then removed the goggles, put a patch over their left eye, put on a nose-clip and began breathing through the Rudolph valve. After breathing the gas mixture for eight minutes, the determination of the scotopic threshold began. This occurred, thus, after a little more than 30 minutes in the dark.

Thresholds were measured with the method of constant stimuli. After the appropriate range had been determined using the method of limits, a series of five or six intensities at 0.1 neutral density intervals was chosen. Each was presented in random order from six to 10 times, depending on the observer's variability. The observers were cautioned that a light would not be presented every time. Catch trials were inserted from time to time, but there was very little guessing. A frequency of seeing curve was calculated and plotted on cumulative probability paper. The 50% point was taken as the threshold.

A threshold measurement took about 5 minutes. Thus, each subject breathed the gas-mixtures for no more than a quarter of an hour.

RESULTS

Figure 1 shows the thresholds for each subject under both 21% and 10% oxygen. In every case, thresholds were worse under the 10% condition. The mean threshold degradation was 0.38 log unit. This decrease was significant according to a paired t-test ($p < .003$).

Five subjects reported dizziness, lightheadedness, air hunger, and restlessness while breathing the 10% oxygen. (The sixth subject reported feeling lightheaded during exposure to 21% oxygen.)

The P_{et,O_2} , P_{et,CO_2} , and SaO_2 remained constant during exposure to 21% oxygen. Under 10% oxygen, the SaO_2 was significantly reduced from 97% to 77% ($p < .001$) in seven minutes, the P_{et,O_2} was reduced from 108 to 42 torr ($p < .001$), and the P_{et,CO_2} remained constant at 34-35 torr. Mean heart rate was faster in 10% oxygen (91 bpm) than in 21% oxygen (82 bpm).

DISCUSSION

There has been considerable controversy as to the level of oxygen deprivation which has a degrading effect on performance. A great deal of work bearing on this question has been done in two separate areas. One deals with the effects of altitude on performance and the other with the effects of carbon-monoxide (CO). The two are related: the amount of oxygen decreases as altitude increases, and the amount of oxygen available in the blood is also reduced by exposure to CO because of the great affinity of hemoglobin for CO.

Some investigators have reported measurable degradations with very small reductions in the amount of oxygen available. Indeed, McFarland (1939) reported that scotopic vision is impaired in proportion to the reduction of ambient PO_2 below 120 torr. In our previous experiments, we found no degradation of scotopic

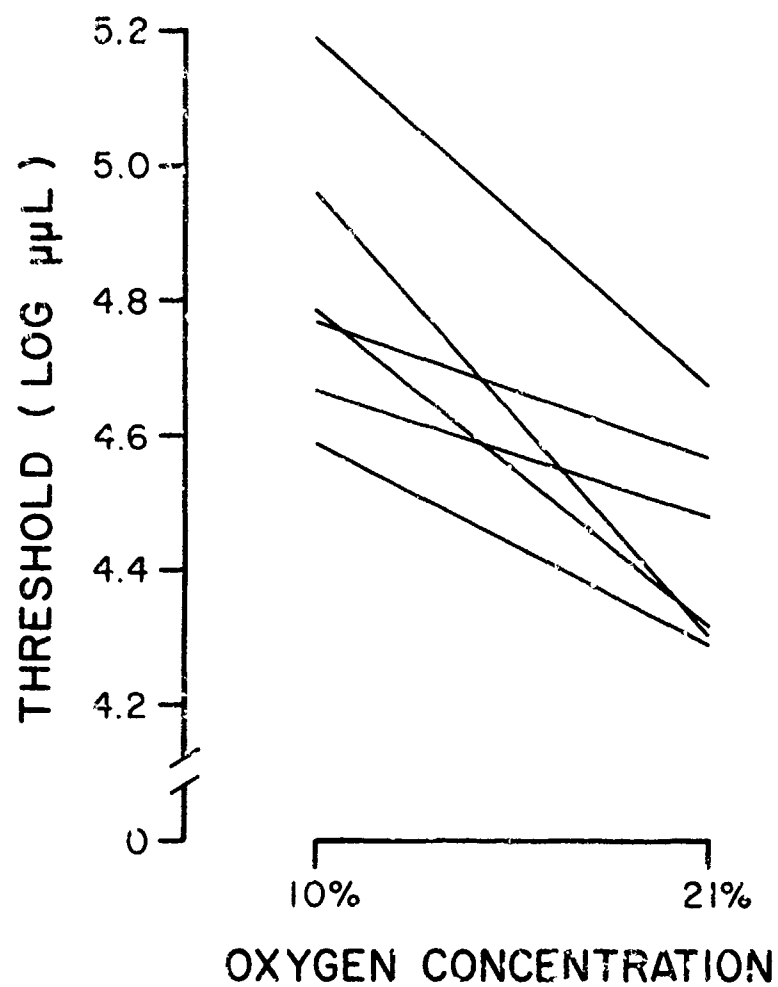


Fig. 1. Visual threshold for each subject under each condition of oxygen concentration.

sensitivity with levels of oxygen reduced to 13% (99 torr). The reduction to 10% (76 torr) in this study, however, produced a clear loss of scotopic sensitivity within 15 minutes.

These results do not, thus, support the contention that scotopic sensitivity is especially sensitive to small reductions in the level of oxygen. Rather, they agree with those findings that show that an appreciable drop in the oxygen level is required to have an effect. Scotopic vision may not be impaired until a sufficient state of hypoxia has been induced. Assuming that our measurements of $P_{et} O_2$ and $P_{et} CO_2$ accurately indicated the alveolar gas partial pressures (Rahn, 1949), this state exists when the alveolar PO_2 is below 43 torr or the SO_2 is less than 77%.

Our results agree with those of such investigators as Gellhorn (1936) who found changes in intensity discrimination only when the oxygen level fell to 10% (76 torr). Similarly, Pierson (1967) found no degradation of night vision below 12,000 feet and reported that "dramatic" changes occurred only at 18,000 feet. Tune (1964) and Fowler et al (1985) have also concluded that the minimum altitude at which perceptual-motor performance is degraded is about 10,000 ft. (An oxygen level of 10% (76 torr) corresponds to an altitude of about 18,000 ft.) Otis et al (1946) found that contrast discrimination was impaired when the alveolar PC_2 was about 40 torr.

The reason for this longstanding disagreement is not clear. But it may be worth noting that, unlike most such studies, the present one was carried out as a double-blind experiment. Ohlbaum (1969) has remarked that a doubleblind procedure is necessary in reported behavioral impairment with small doses of CO, but subsequently could not replicate these results with a doubleblind design, according to Stewart et al (1973).

What causes the reduction in scotopic sensitivity when the oxygen level is reduced? McFarland and Evans (1939) observed that the inhalation of oxygen quickly restored the scotopic sensitivity of hypoxic subjects. Consequently, they postulated that hypoxia interfered with neural transmission of visual information. Otis et al (1946) postulated that hypoxia and hypocapnia additively

impaired contrast sensitivity. Our data, however, show that the $P_{et}CO_2$ was not changed by exposure to 10% oxygen (76 torr). Hypocapnia could not, therefore, have had an effect. We conclude that hypoxia, not hypocapnia, impaired scotopic sensitivity.

ACKNOWLEDGMENT

We thank James Dougherty and HMI Daniel Francis for measuring the expired gases and the arterial levels of oxygen.

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GLOSSARY OF TERMS

COHb-- Carboxyhemoglobin in the blood.

Double-blind-- Withholding information about the independent variables of an experiment from both the subjects and the investigators who gather the data.

End-tidal-- The end of ventilatory expiration.

Hypocapnia-- A reduction from normal in the amount of carbon-dioxide in the blood.

Hypoxia-- A reduction from the normal amount of oxygen in the tissues.

Log uuL-- The logarithm, base 10, of light intensity measured in micro-micro-Lamberts.

P_{CO_2} -- The partial pressure of carbon-dioxide in the supply of breathing gas.

P_{et,CO_2} -- The end-tidal partial pressure of carbon-dioxide in exhaled air.

PO_2 -- The partial pressure of oxygen in the supply of breathing gas.

P_{et,O_2} -- The end-tidal partial pressure of oxygen in exhaled air.

SaO₂ -- The extent to which the hemoglobin in arterial blood has combined (saturated) with molecular oxygen, usually expressed as percent.

Scotopic vision-- Vision at very low levels of luminance (about log -5 mL or below) mediated only by rods of the retina.

Torr-- A unit of pressure equivalent to 1/760th of an atmosphere; also equivalent to 1 mm Hg pressure.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NSMRL # 1097	2. GOVT ACCESSION NO. AD-A183973	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SCOTOPIC SENSITIVITY WITH 10% OXYGEN		5. TYPE OF REPORT & PERIOD COVERED Interim report
7. AUTHOR(s) S. M. Luria and Douglas R. Knight		6. PERFORMING ORG. REPORT NUMBER NSMRL Report 1097
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Submarine Medical Research Laboratory Naval Submarine Base New London Groton, CT 06349-5900		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Medical Research & Development Com. NMCNCR, Bethesda, MD 20814-5044		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS M0100.001-1023
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE 9 July 1987
		13. NUMBER OF PAGES 11
		15. SECURITY CLASS (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) scotopic sensitivity; hypoxia; hypocapnia ←		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The night vision (scotopic) sensitivity of 6 subjects was measured while they were breathing either air (21% oxygen, PO ₂ 160 torr) or 10% oxygen, balance nitrogen (PO ₂ 76 torr. Continuous monitoring showed that the mean oxygen content in the arterial blood (SaO ₂) dropped from 97% to 77% during the first seven minutes of breathing 10% oxygen, and there was a significant degradation of scotopic sensitivity. The reduced sensitivity was attributed solely to hypoxia with no		

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